

**PN JUNCTION
DIODES AND
RECTIFIER CIRCUITS**

AE

Naval Air Technical Training Command

CNATT-J121 PAT

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

test, but a learning situation. There will always be an instructor available to answer any questions you might have concerning the information being presented.

You will proceed from page to page, as in a conventional book. On each page, you will find one or more numbered sections. These sections are called "frames." You will go from frame to frame, using a piece of paper to cover upcoming frames. There is no advantage in peeking at new information. To be effective, you must follow the sequence. You must respond to each frame before you uncover the correct response. AFTER writing or selecting your response, be sure to check the left side of the next frame to see if your response was correct.

If your response was wrong, strike it out, reread the frame, and select another response. If your response was correct, continue with the next frame.

At the end of this program, there is a self-test to check what you have gained from the lesson.

Turn to page ii and read the objectives.

SUGGESTED READING TIME 90 MINUTES

The student will:

1. Select, from a list of statements, the one which describes the forming of a PN junction.
2. Select, from a list of statements, the one which defines junction resistance.
3. Select, from a list of statements, the one which defines forward bias.
4. Select, from a list of statements, the one which defines reverse bias.
5. Select, from a list of statements, the one which describes current flow in the external circuit.
6. Select, from a list of statements, the operating limitations of a PN junction diode.
7. Complete a PN junction diode circuit by drawing in the symbol for the PN junction diode to indicate forward bias.
8. Select, from a list of statements, the purpose of a rectifier.
9. Compute the average voltage output of a half-wave rectifier for a given maximum secondary voltage.
10. Write the formula for computing the average value of output voltage for a full-wave rectifier.
11. Compute the average voltage output of a four-diode full-wave bridge rectifier for a given maximum secondary voltage.

features of semiconductor diodes compared to vacuum tubes.

diode. Semiconductor diodes are used for rectifiers and detectors.

It is convenient to speak of PN junctions as being "joined" together. Actually, a PN junction is formed during a manufacturing process in which the P-type and the N-type material form a single crystal. A PN junction diode would not work if the materials were mechanically joined.

When P-type and N-type semiconductor materials are joined together, a _____ is formed.

PN junction

2. Select, from the statements below, the one which describes the forming of a PN junction. Circle the letter preceded by your choice.

a. When P-type and N-type materials are placed together in a semiconductor diode.

b. When P-type and N-type materials are joined together in a semiconductor diode.

ACCEPTOR atom into germanium. The trivalent acceptor atom entering into covalent bond with surrounding germanium atoms accepts an electron from a neighboring atom, creating a hole. This action causes the acceptor atom to become a negative ion.

When an acceptor atom was injected into the germanium, an electron was removed from a neighboring atom, creating a _____ in the P-type material.

hole

4. The P-type material has an overall neutral charge. For every negative ion that is created, there is also a positive hole to compensate for it.



○ Holes

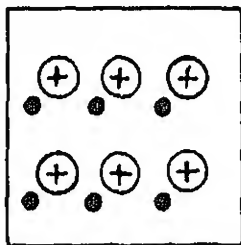
The negative ions in the P-type material are neutralized by the same number of positively charged holes; therefore, the P-type material has an overall _____ electrical charge.

neutral or
zero

5. The N-type material of a semiconductor diode is created by injecting a DONOR atom into germanium. The pentavalent donor atom enters into covalent bond with neighboring germanium atoms, leaving an electron that is free to move about. This action causes the donor atom to become a positive ion.

6. The N-type material has an overall neutral electrical charge. For every positive ion created, there is an electron to compensate for it.

Note the drawing of N-type material.



⊕ Positive ion

● Free electron

For each positive ion present, a free electron neutralizes its electrical charge; therefore, the N-type material has an overall _____ electrical charge.

are electrons.

The majority carriers in P-type material are holes, and the minority carriers are _____.

electrons

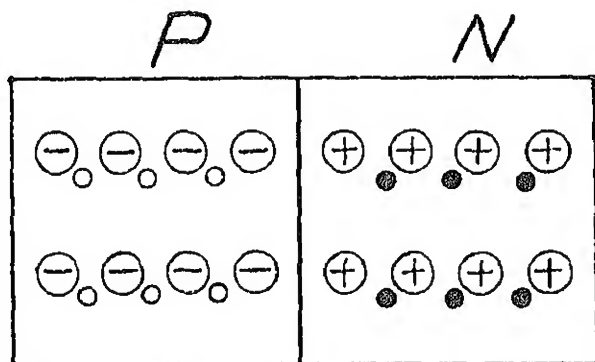
The majority carriers in N-type material are electrons, and the minority carriers are _____.

holes

The majority carriers in P-type material are _____, and the majority carriers in N-type material are _____.

are joined together, the holes and electrons nearest the junction will combine. When these majority carriers combine, they will leave uncompensated ions. (Remember, the ions are held in covalent bonds and are unable to move about within the crystalline structure.)

Note the drawing below.



The N-type material was initially neutral, and the loss of some of its electrons will leave it with a _____ (negative/positive) charge.

N-type material, the P-type material will have a _____ (negative/positive) charge.

negative

When additional electrons from the N-type material attempt to approach the junction, they will be repelled by the _____ charge of the P-type material.

negative

If holes from the P-type material attempt to approach the junction, they will be repelled by the _____ charge of the N-type material.

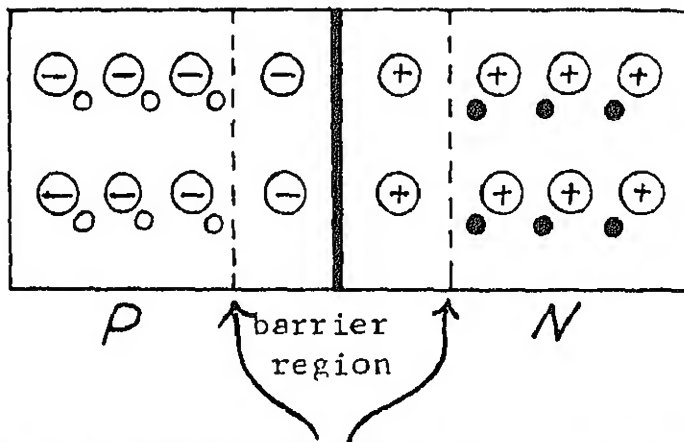
will have an absence of _____
and _____.

holes

free electrons

9. The absence of holes and free electrons near the junction leaves uncompensated ions. Since the uncompensated ions at the junction repel further attempts of majority carriers to combine, and there is an absence or depletion of majority carriers, this area is known as the depletion or barrier region.

Note the drawing below.



and the N-type material with a positive charge. This difference in potential may be represented by a small battery and is referred to as the barrier potential.

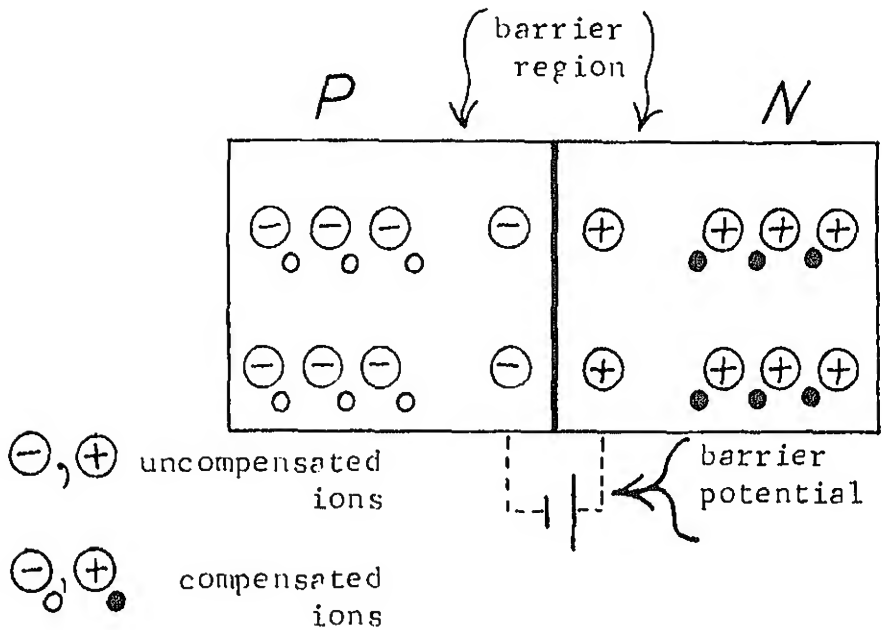
The depletion or barrier region is the area near the junction which has an absence of _____ and _____.

holes

free electrons

The difference in potential, caused by the loss of holes and free electrons, is referred to as the _____.

depletion region and the barrier potential as a small battery.



In PN junction diodes, the loss of holes in the P-type material will give the P-type material a _____ (positive/negative) charge.

_____ (positive/negative)
charge.

positive

The loss of holes and free electrons in the area near the PN junction causes a difference in potential, referred to as the _____
_____.

barrier
potential

11. The combining of holes and electrons near the junction left uncompensated ions and caused the barrier potential which offers an opposition to the further combining of majority carriers. This opposition, near the junction, is commonly referred to as junction resistance.

but will be repelled by the positively charged _____ in the N-type material.

s

The formation of a PN junction in semiconductor material will occur when the majority carriers nearest the junction combine and a _____ potential is established which will prevent further _____.

rier
bination

When a barrier potential is established in semiconductor material by combining the majority carriers in the P-type and the N-type material, a(n) _____ is formed.

the _____.

junction
resistance
or
barrier
potential

Once the PN junction is formed, the junction resistance (barrier potential) is the opposition offered to the further combining of _____.

majority
carriers

The opposition offered to the further combining of majority carriers, once the PN junction is formed, is the _____.

letter preceding your choice.

- a. The opposition offered to the further combining of minority carriers, once the PN junction is formed.
- b. The opposition offered to the further combining of majority carriers, once the PN junction is formed.
- c. The opposition offered to the further combining of uncompensated ions, once the PN junction is formed.

b. is correct. 14. When a battery is connected to a PN junction, the battery bias the junction with a voltage which

CONTINUE ON PAGE

the _____.

junction
resistance
or
barrier
potential

Once the PN junction is formed, the
junction resistance (barrier potential)
is the opposition offered to the
further combining of _____.

majority
carriers

The opposition offered to the further
combining of majority carriers, once
the PN junction is formed, is the
_____.

once the PN junction is formed.

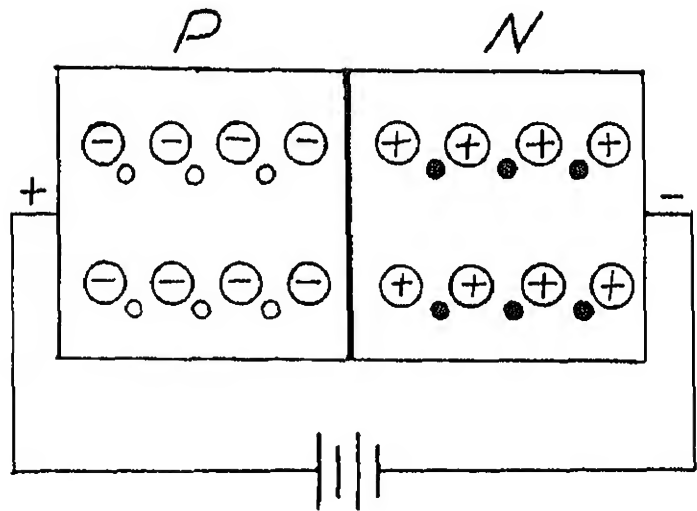
- b. The opposition offered to the further combining of majority carriers, once the PN junction is formed.
- c. The opposition offered to the further combining of uncompensated ions, once the PN junction is formed.

is correct.

14. When a battery is connected across the PN junction, the battery potential will bias the junction. (Bias is a d.c. voltage which sets the operating level.)

CONTINUE ON PAGE 16.

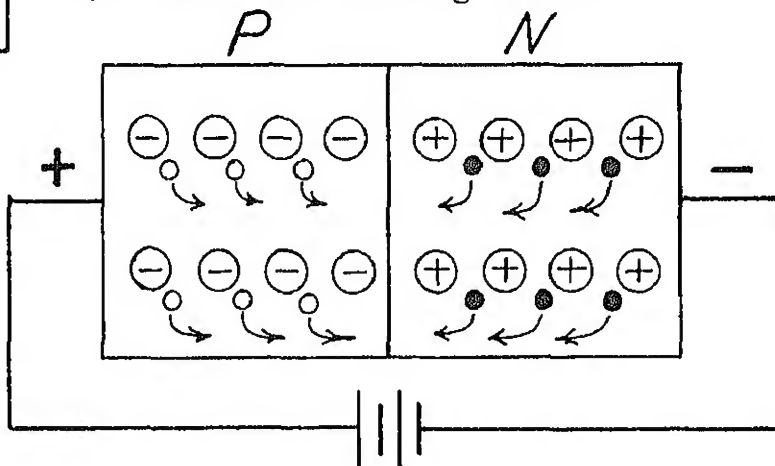
(low resistance).
Forward bias is applied to a PN junction by connecting the positive battery terminal to the P-type material and the negative terminal to the N-type material. Note the drawing below.



said to be biased in the _____
(forward/reverse) direction.

ard

15. Note the drawing below.



The positive potential on the P-type material will repel holes toward the junction. The negative potential on the N-type material will repel electrons toward the junction. Forward bias will reduce the barrier potential and allow the majority carriers to cross the junction, therefore aiding conduction.

(negative/positive) battery terminal and the N-type material is connected to the _____ (negative/positive) battery terminal.

positive
negative

The application of forward bias to a PN junction diode will aid conduction by _____ (aiding/opposing) the barrier potential.

opposing

A PN junction diode will be biased in the forward direction when the negative battery terminal is connected to the _____-type material and the positive battery terminal is connected to the _____-type material.

barrier potential.

oppose

Forward bias will _____
(increase/decrease) barrier potential.

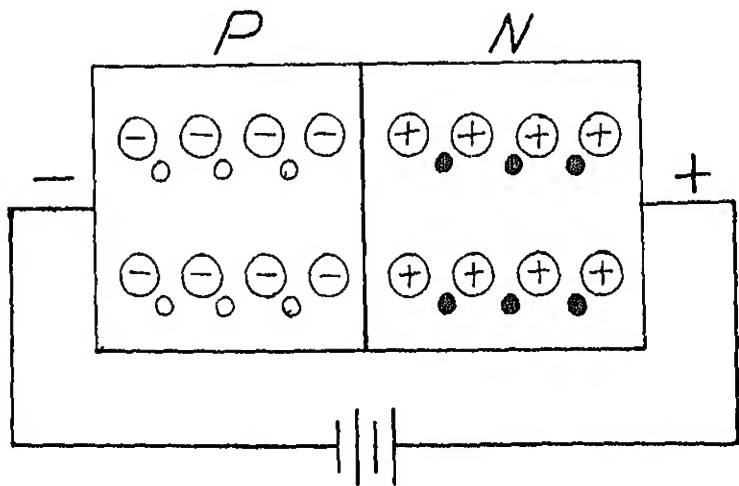
decrease

16. Select, from the list of statements, the definition of forward bias. Circle the letter preceding your choice.

- a. Opposes conduction by opposing the barrier potential.
- b. Opposes conduction by aiding the barrier potential.
- c. Aids conduction by opposing the barrier potential.
- d. Aids conduction by aiding the barrier potential.

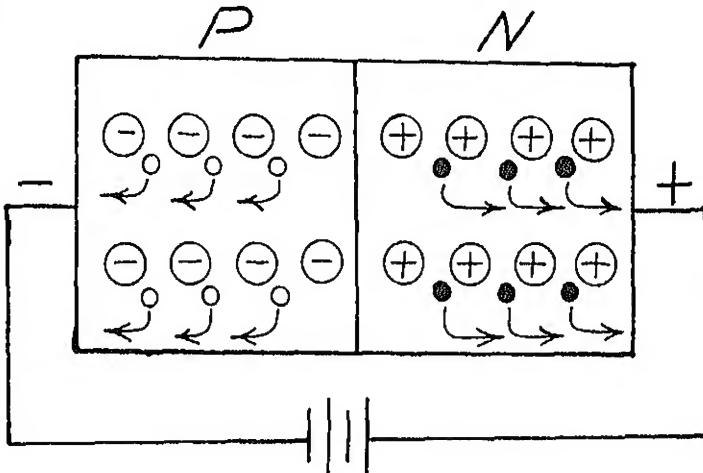
conduction through the junction, and the junction is said to be biased in the reverse direction (high resistance).

Reverse bias is applied to a PN junction by connecting the positive battery terminal to the N-type material and the negative terminal to the P-type material. Note the drawing below.



said to be biased in the _____
(forward/reverse) direction.

18. Note the drawing below.



The negative potential on the P-type material will attract holes away from the junction, and the positive potential on the N-type material will attract electrons away from the junction. Reverse bias will increase the barrier potential and oppose conduction of majority carriers across the junction.

(negative/positive) battery terminal and the N-type material is connected to the _____ (negative/positive) battery terminal.

negative
positive

The application of reverse bias to a PN junction diode will oppose conduction by _____ (aiding/opposing) the barrier potential.

aiding

A PN junction diode will be biased in the reverse direction when the negative battery terminal is connected to the _____-type material and the positive battery terminal is connected to the _____-type material.

carriers away from the junction and
_____ (aid/oppose) the
barrier potential.

d

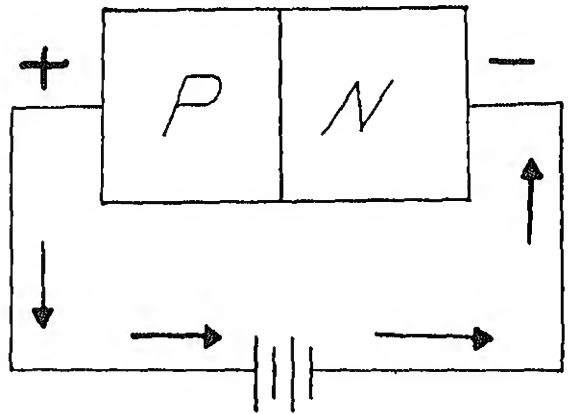
Reverse bias will _____
(increase/decrease) barrier potential.

increase

19. Select, from the list of statements, the
definition of reverse bias. Circle the
letter preceding your choice.

- a. Opposes conduction by opposing the
barrier potential.
- b. Opposes conduction by aiding the
barrier potential.
- c. Aids conduction by opposing the
barrier potential.
- d. Aids conduction by aiding the
barrier potential.

from the negative battery terminal.
to the positive battery terminal.
Note the drawing below.



With forward bias applied to the diode,
current will flow from _____
to _____.

negative
positive

Current will flow, in the external
circuit, with _____ (forward
reverse) bias applied to the diode.

potential, preventing conduction, and will not allow current to flow in the external circuit.

Current will not flow, in the external circuit, with _____ (forward/reverse) bias applied to the diode.

erse

The diode will conduct with _____ (forward/reverse) bias applied, allowing current to flow in the external circuit, and will not conduct with _____ (forward/reverse) bias applied.

preceding your choice.

- a. In the external circuit, with forward bias applied to a diode, current flows from positive to negative.
- b. In the external circuit, with reverse bias applied to a diode, current flows from positive to negative.
- c. In the external circuit, with reverse bias applied to a diode, current flows from negative to positive.
- d. In the external circuit, with forward bias applied to a diode, current flows from negative to positive.

types of semiconductor materials. When forward bias is applied to a diode, conduction is due to the majority carriers being repelled toward the junction. When reverse bias is applied to a diode, conduction is opposed owing to the majority carriers being attracted away from the junction.

Remembering that the minority carriers in the P-type material are electrons, the minority carriers in the N-type material must be _____.

the only current that can flow is a
conduction of minority carriers and
in the opposite direction of majorit
carrier current flow. Increasing th
reverse-bias voltage will increase t
minority current flow.

The amount of reverse-bias voltage t
causes excessive minority current fl
is called the breakdown voltage of a
diode.

The increase in reverse bias that ca
excessive minority current flow is
called the _____
of a diode.

called the _____
of a diode.

25. Breakdown voltage is one of three limitations to the application of diodes. Each diode has its breakdown voltage listed by the manufacturer.

Another limitation is current. Current flow in the forward (low resistance) direction or reverse (high resistance) direction will cause heat in the diode. As current increases, the heat will also increase and eventually destroy the diode.

When current flows in a diode,
_____ is generated.

current

Two limitations in the application of diodes are _____ voltage a

breakdown
current

26. A major limitation in the application of a diode is its temperature sensitivity. If, during the operation of a diode, the external or internal temperature is allowed to increase, the internal resistance of the diode will decrease. As the internal resistance decreases, the current through the diode increases and permanent damage results.

As the temperature of a diode increases, the internal resistance _____


crease


A major limitation in the operation of a diode is its _____ sensitivity.

perature

27. Select, from the list below, the operating limitations of a diode. Circle the letter(s) preceding your choice(s).

- a. Breakdown voltage
- b. Crystal defects
- c. Junction resistance
- d. Temperature
- e. Ions
- f. Current

and the vertical line,  , represents the N-type material or cathode. Electron flow, in a semiconductor diode, is from the N-side to the P-side.

The direction of electron flow, relative to the symbol,  , is always _____ (with/against) the arrow.

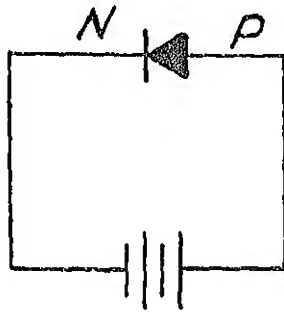
against

In the drawing below, the P-side and the N-side are labeled, and the direction of current flow is shown.




direction of current flow

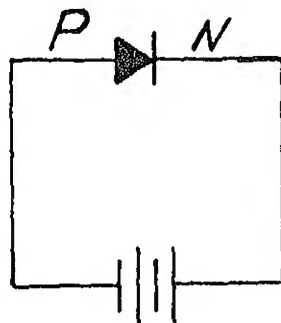
Normal current flow through a diode is _____ (with/against) the arrow.



The circuit above is biased in the
 _____ direction.

ward

30. The circuit below represents a reverse-biased semiconductor diode.

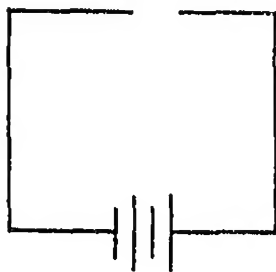


The circuit above is biased in the
 _____ direction.

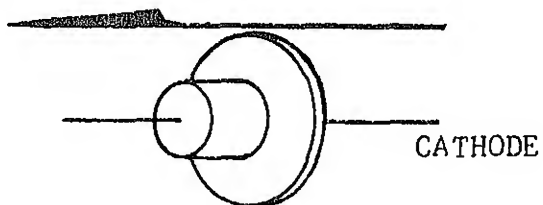
represents the _____ (anode/
cathode).

anode
cathode

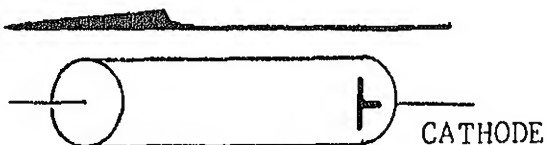
32. Draw a semiconductor diode symbol in
the circuit below to indicate forward
bias.



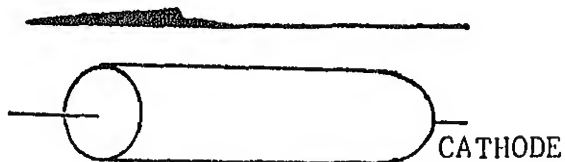
normal current flow



normal current flow



normal current flow



The cathode of most semiconductor diodes is usually identified by its shape or a mark, as shown in the illustrations above.

NO RESPONSE REQUIRED.

istics of low forward resistance and high reverse resistance. These two properties of PN junction diodes will allow them to be used as rectifiers.

A rectifier is a device that converts an a.c. input voltage into a pulsating d.c. output voltage.

The properties of a PN junction diode that allow it to be used as a rectifier are its _____ (high/low) reverse resistance and its _____ (high/low) forward resistance.

direction only.

An a.c. signal voltage applied to a rectifier will be converted to a pulsating d.c. voltage, because current only flows in one _____ through a rectifier.

A rectifier will convert _____
(a.c./d.c.) to pulsating _____
(a.c./d.c.).

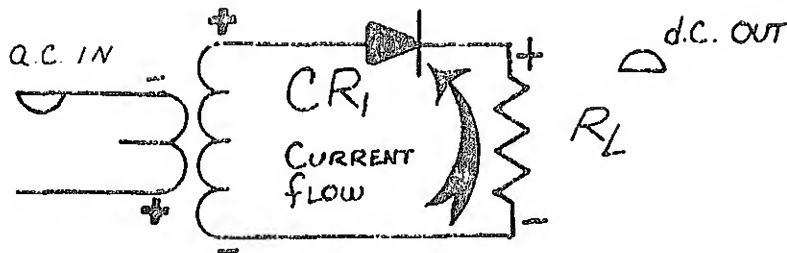
The conversion of an a.c. input signal voltage to a pulsating d.c. output voltage is accomplished by using a(n) _____.

- a. Converts a pulsating d.c. input voltage to an a.c. output voltage.
- b. Converts an a.c. input voltage to pulsating d.c. output voltage.
- c. Converts an a.c. output voltage to a pulsating d.c. input voltage.
- d. Converts a pulsating d.c. output voltage to an a.c. input voltage.

b. is correct.

37. Keep in mind that there is a phase inversion across the windings of a transformer. The polarities of the first half-cycle are not circled, but the polarities of the second half-cycle are circled.

NO RESPONSE REQUIRED.



The diode will allow current to flow when the top of the transformer secondary is positive (forward bias).

Majority-carrier current will flow through the load resistor (R_L) when the diode is biased in a _____ (reverse/forward) direction.

39. Since the purpose of a rectifier is to convert an a.c. voltage to a pulsating d.c. voltage and current only flows through the load when the diode is forward-biased, the output will be pulsating d.c.



During the second half-cycle, current will not flow through R_L , because the diode is _____-biased.

reverse

40. An input of one cycle results in an output of one d.c. pulse. The output ripple frequency of a half-wave rectifier is equal to the input frequency.

For an a.c. input signal of four cycles to a half-wave rectifier, the output would be _____ d.c. pulses.

four

41. The average value of output voltage of a half-wave rectifier is equal to .318 times E_{max} of the secondary.

$$(E_{avg} = E_{max} \text{ times } .318.)$$

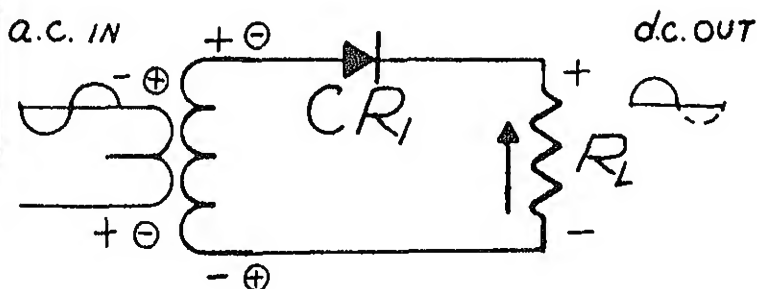
The output ripple frequency of a half-wave rectifier is equal to the _____ frequency.

The formula for computing the average value of output voltage of a half-wave rectifier is _____.

.318

42. Compute, for the circuit below, the average output voltage.

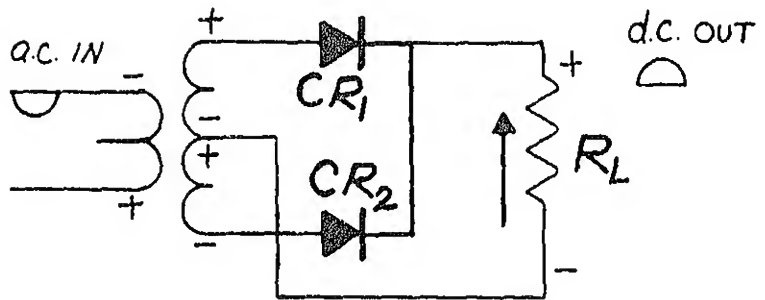
E_{\max} of the secondary is 110 volts a.c.




$E_{\text{avg}} = \rule{1.5cm}{0.4pt}$ volts d.c.

tapped, the maximum voltage for each part of the rectifier circuit will be exactly half of the secondary voltage.

Shown below is a two-diode full-wave rectifier circuit.



With a negative-going signal applied to the primary, CR_1 will conduct, because forward bias is applied. Current flow will be from the transformer center tap up through R_L , through CR_1 , to the top of the transformer.



With a positive-going signal applied to the primary, CR_2 will conduct, because it has forward bias applied. Current flow will be from the transformer center tap up through R_L , through CR_2 , to the bottom of the transformer. Current will not flow through CR_1 this time, because reverse bias is applied to it.

CR_1 will conduct when the top of the secondary is _____
(positive/negative).

ive

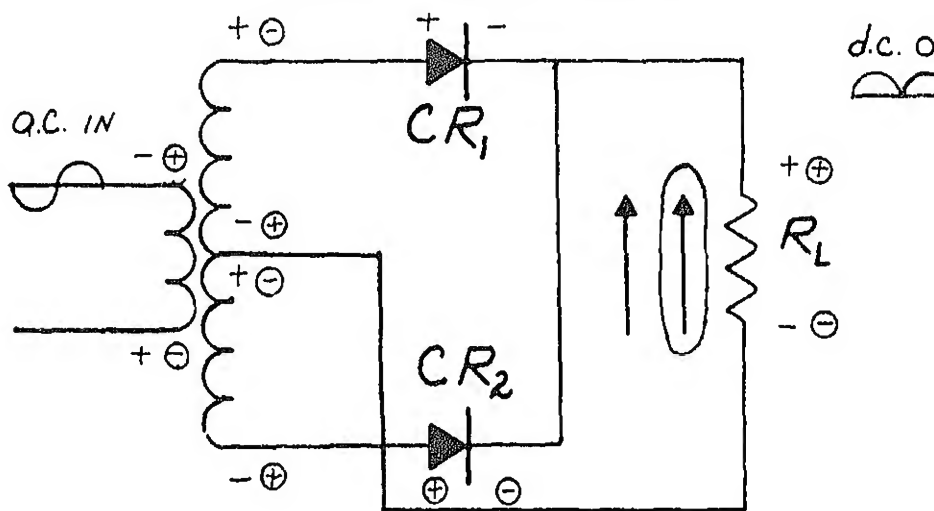
CR_2 will conduct when the bottom of the secondary is _____
(positive/negative).

(forward/reverse) biased.

forward

1.1 The full-wave rectifier will allow current flow through the load resistor (R_L) during the application of a positive or negative-going signal voltage.

Study the circuit below.



An input signal of one cycle results in an output of two d.c. pulses. The output ripple frequency of a full-wave rectifier is equal to twice the input frequency.

t

45. The average value of output voltage of a full-wave rectifier is equal to .636 times E_{\max} of the secondary.

($E_{\text{avg}} = E_{\max} \times .636$). Remember, the transformer secondary of the full-wave rectifier is center-tapped. Therefore, the voltage applied to the conducting diode will be half of the secondary voltage.

An operating rectifier with a secondary voltage of 110 volts a.c. will have an average output pulse voltage of 34.98 volts d.c. (E_{\max} will be half of the secondary voltage.)

substituting.

secondary voltage = 110 volts a.c.

E_{max} for the circuit conducting will
be 55 volts a.c.

$$E_{avg} = 55 \times .636$$

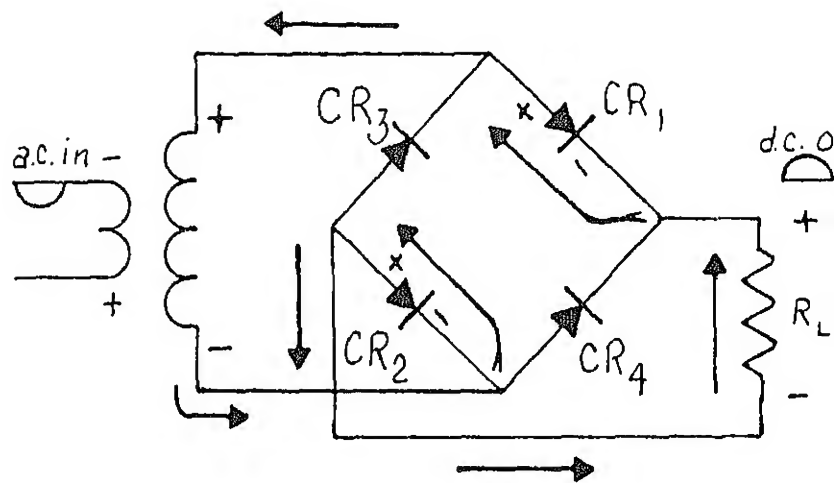
therefore,

$$E_{avg} = 34.98 \text{ volts d.c.}$$

An operating rectifier with a secondary voltage of 220 volts a.c. would provide an input voltage to one-half of the rectifier circuit of 110 volts a.c., and the resultant average output voltage would be _____ volts d.c.

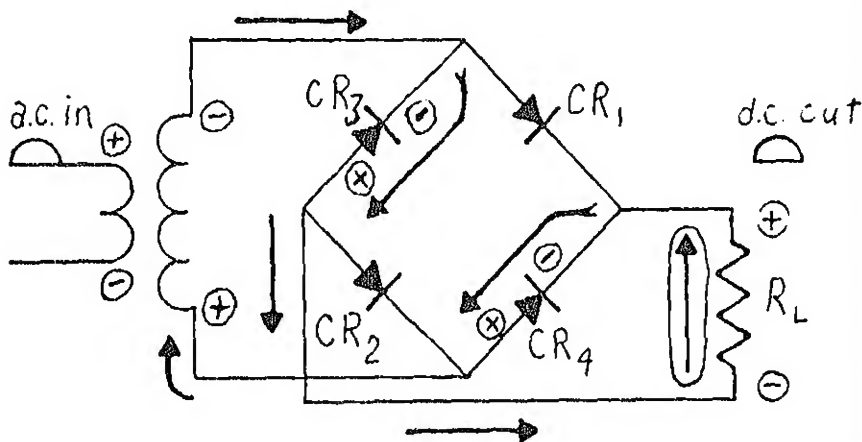
47. The full-wave bridge rectifier uses four PN junction diodes, and the transformer secondary is not center-tapped. The resultant average voltage outputs will be higher, because all of the secondary voltage is applied to the rectifier.

The advantage of using the four-diode full-wave bridge rectifier over the two-diode full-wave rectifier is the _____ (higher/lower) average voltage output.



With a negative-going input signal to the primary of the full-wave bridge rectifier circuit, CR₃ and CR₄ will not conduct, because they are reverse biased. CR₁ and CR₂ will conduct, because they are _____-bias

conduct. Note the current flow in the circuit below.



The output pulses of the full-wave bridge rectifier are identical with the output pulses of the rectifier using only two diodes. The output ripple frequency of a full-wave rectifier is equal to twice the input frequency.

The advantage of using the four-diode full-wave bridge rectifier over the two-diode full-wave rectifier is the average voltage output is _____.

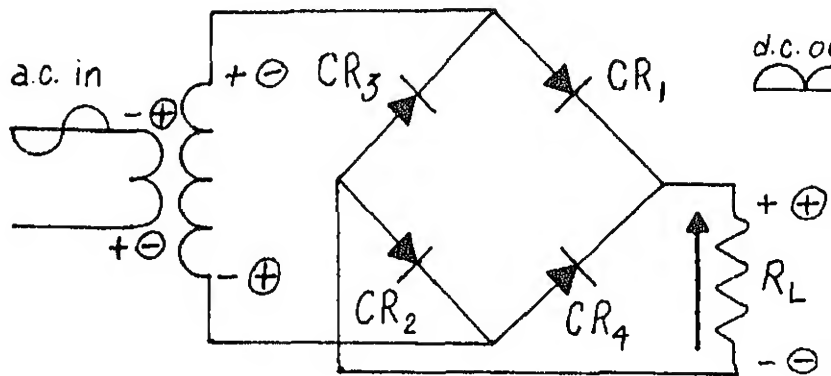
$$E_{avg} = E_{max} \times .636$$

A secondary voltage of 110 volts a.c.
in a full-wave bridge rectifier circuit
would result in an average output of
_____ volts d.c.

69.96

51. Compute, for the circuit below, the
average output voltage.

E_{max} of the secondary = 220 volts a.c.



$E_{avg} =$ _____ volts d.c.

the diode. The peak reverse voltage (PRV) is the maximum reverse-bias voltage which may be applied to a diode and should be three times the value of the signal source voltage, owing to the capacitance of the circuitry.

The maximum reverse-bias voltage which may be applied to a diode is called the _____ rating.

erse
(PRV)

The peak reverse voltage (PRV) which may be applied to a diode is the maximum amount of _____ (forward/reverse) bias.

peak reverse
voltage (PRV)

53. The major factor to consider when selecting diodes for use in rectifier circuits is the _____
_____.

peak reverse
voltage (PRV)

54. There are several desirable features of semiconductor diodes over vacuum tubes. Because of the extremely small size and the light weight of the semiconductor diode, a considerable saving in the size and the weight of equipment is achieved.

Two desirable features of a semiconductor diode over a vacuum tube are the _____ and the _____.

diode, the internal resistance is very low. Compared to a vacuum tube, there is less power loss because of heat.

Three desirable features of semiconductor diodes compared to vacuum tubes are the small size, the light weight, and the low _____.

56. The fourth desirable feature of a semiconductor diode is the long life.

Because of the semiconductor diode's solid construction, life expectancy is very long.

Four desirable features of semiconductor diodes compared to vacuum tubes are the light weight, the small size, the low internal resistance, and the _____.

the letter(s) preceding your choice(s)

- a. light weight
- b. High internal resistance
- c. Long life
- d. Low internal resistance
- e. Large size
- f. Short life
- g. Small size
- h. Heavyweight

e., c., d.,
and g. are
correct.

58. The major applications of PN junction diodes are signal detectors and power supply rectifiers. In this program, only rectifiers have been studied. Signal detectors will be covered in another lesson. A self-test begins on page 55.

NO RESPONSE REQUIRED.

describes the forming of a PN junction. Circle the letter preceding your choice. (Frame 1)

- a. When the P-type and the N-type material are placed together in a semiconductor diode.
- b. When the P-type and the N-type material are joined together in a semiconductor diode.

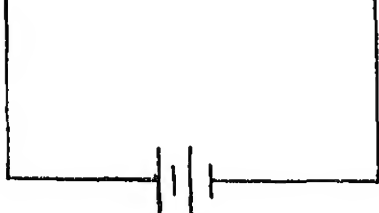
2. Select, from the list of statements, the definition of junction resistance (barrier potential). Circle the letter preceding your choice. (Frame 3)

- a. The opposition offered to the further combining of majority carriers, once the PN junction is formed.
- b. The opposition offered to the further combining of minority carriers, once the PN junction is formed.
- c. The opposition offered to the further combining of uncompensated ions, once the PN junction is formed.

3. Select, from the list of statements, the definition of forward bias. Circle the letter preceding your choice. (Frame 14)

- a. Opposes conduction by opposing the barrier potential.
- b. Opposes conduction by aiding the barrier potential.
- c. Aids conduction by aiding the barrier potential.
- d. Aids conduction by opposing the barrier potential.

- b. Aids conduction by opposing the barrier potential.
 - c. Opposes conduction by aiding the barrier potential.
 - d. Opposes conduction by opposing the barrier potential.
5. Select, from the list of statements, the one that describes current flow in the external circuit. Circle the letter preceding your choice. (Frame 20)
- a. With forward bias applied to a diode, current flows from positive to negative in the external circuit.
 - b. With forward bias applied to a diode, current flows from negative to positive in the external circuit.
 - c. With reverse bias applied to a diode, current flows from positive to negative in the external circuit.
 - d. With reverse bias applied to a diode, current flows from negative to positive in the external circuit.
6. Select, from the list below, the operating limitations of a diode. Circle the letter(s) preceding your choice(s). (Frame 24)
- a. Breakdown voltage
 - b. Crystal defects
 - c. Temperature
 - d. Current
 - e. Junction resistance
 - f. Bias



8. Select, from the list below, the purpose of a rectifier. Circle the letter preceding your choice. (Frame 34)
- a. Converts a pulsating d.c. output voltage to an a.c. input voltage.
 - b. Converts a pulsating d.c. input voltage to an a.c. output voltage.
 - c. Converts an a.c. output voltage to a pulsating d.c. input voltage.
 - d. Converts an a.c. input voltage to a pulsating d.c. output voltage.
9. Compute the average voltage output of a half-wave rectifier for a maximum secondary voltage of 110 volts a.c. (Frame 38)
- $E_{avg} =$ _____
10. Write, on the line provided, the formula for computing the average value of output voltage for a full-wave rectifier. (Frame 43)
- _____

$E_{avg} = \underline{\hspace{2cm}}$

12. Complete the statement: The major factor to consider when selecting diodes for use in rectifier circuits is the _____ ratio
(Frame 52)
13. Select, from the list below, the desirable feature(s) of semiconductor diodes compared to vacuum tubes. Circle the letter(s) preceding your choice(s).
(Frame 54)
- a. High internal resistance
 - b. Low internal resistance
 - c. Large size
 - d. Short life
 - e. Long life
 - f. light weight
 - g. Small size
 - h. Heavyweight

